

CLAIMS

1. A multi-layer piezoelectric element comprising:

a stack formed by stacking at least one piezoelectric
5 layer and a plurality of internal electrodes consisting of
first and second internal electrodes alternately one on
another;

a first external electrode which is formed on a first
side face of the stack and is connected to the first internal
10 electrode; and

a second external electrode which is formed on a second
side face of the stack and is connected to the second
internal electrode,

wherein a bonding strength between the piezoelectric
15 layer and the internal electrode is controlled to be weaker
than a bending strength of the piezoelectric layer.

2. The multi-layer piezoelectric element according to
claim 1,

20 wherein the bonding strength between the piezoelectric
layer and the internal electrode is 70 MPa or less.

3. The multi-layer piezoelectric element according to
claims 1 or 2,

25 wherein a bonding strength between the first external

electrode and the internal electrode and a bonding strength between the second external electrode and the internal electrode are larger than the bonding strength between the piezoelectric layer and the internal electrode.

5

4. A multi-layer piezoelectric element comprising:
a stack formed by stacking at least one piezoelectric layer and a plurality of internal electrodes consisting of first and second internal electrodes alternately one on another;

10

a first external electrode which is formed on a first side face of the stack and is connected to the first internal electrode; and

15

a second external electrode which is formed on a second side face of the stack and is connected to the second internal electrode,

20

wherein the internal electrode includes voids and proportion of an area occupied by the voids to a total area of a cross section of the internal electrode is in a range from 5 to 70%.

5. A multi-layer piezoelectric element comprising:
a stack formed by stacking at least one piezoelectric layer and a plurality of internal electrodes consisting of first and second internal electrodes alternately one on

25

another;

a first external electrode which is formed on a first side face of the stack and is connected to the first internal electrode; and

5 a second external electrode which is formed on a second side face of the stack and is connected to the second internal electrode,

wherein voids are formed to penetrate through the internal electrode in the direction of stacking.

10

6. The multi-layer piezoelectric element according to claim 5,

wherein all of the internal electrodes are provided with the voids.

15

7. The multi-layer piezoelectric element as in one of claims 4-6,

wherein an angle between a boundary of the electrode and the piezoelectric layer and a boundary of the electrode and the void in a interface between the internal electrode and the piezoelectric layer is 60 degrees or more.

20

8. The multi-layer piezoelectric element as in one of claims 4-7,

25 wherein an inorganic composition which includes BN as

the main component is added to the internal electrode.

9. A multi-layer piezoelectric element comprising:

a stack formed by stacking at least one piezoelectric
5 layer and a plurality of internal electrodes consisting of
first and second internal electrodes alternately one on
another;

a first external electrode which is formed on a first
side face of the stack and is connected to the first internal
10 electrode; and

a second external electrode which is formed on a second
side face of the stack and is connected to the second
internal electrode,

wherein an opposed portion in which the first internal
15 electrode and the second internal electrode oppose each other
has a configuration not in line symmetry.

10. The multi-layer piezoelectric element according to
claim 9,

20 wherein the opposed portion has a configuration of
point symmetry.

11. The multi-layer piezoelectric element according to
claims 9 or 10,

25 wherein each of the first internal electrodes has a end

portion located away from one side face to be insulated from the second external electrode formed on said one side face, and

wherein each of the second internal electrodes has a
5 end portion located away from the other side face to be insulated from the first external electrode formed on said other side face.

12. The multi-layer piezoelectric element as in one of
10 claims 9-11,

wherein a distance between the first internal electrode and the second external electrode is set in a range from 0.1 to 5 mm, and a distance between the second internal electrode and the first external electrode is set in a range from 0.1
15 to 5 mm.

13. The multi-layer piezoelectric element as in one of claims 9-12,

wherein a part of the first internal electrode is
20 exposed on one side face of the stack on which the second external electrode is formed and a shortest distance between the exposed part of the first internal electrode and the second external electrode on said one side face of the stack is set in a range from 0.1 to 5 mm,

25 wherein a part of the second internal electrode is

exposed on the other side face of the stack on which the first external electrode is formed and a shortest distance between the exposed part of the second internal electrode and the first external electrode on said other side face of the stack is set in a range from 0.1 to 5 mm.

14. A multi-layer piezoelectric element comprising:
a stack formed by stacking at least one piezoelectric layer and a plurality of internal electrodes consisting of first and second internal electrodes alternately one on another;
a first external electrode which is formed on a first side face of the stack and is connected to the first internal electrode; and
a second external electrode which is formed on a second side face of the stack and is connected to the second internal electrode,
wherein an edge of the first internal electrode which opposes the second external electrode has an arc shape and an edge of the second internal electrode which opposes the first external electrode has an arc shape.

15. The multi-layer piezoelectric element according to claim 14;
wherein a center of said arc shape is within the

internal electrode.

16. The multi-layer piezoelectric element according to claim 14;

5 wherein a center of said arc shape is out of the internal electrode.

17. The multi-layer piezoelectric element as in one of claims 14-16,

10 wherein a corner of an opposed portion in which the first inner electrode and the second inner electrode oppose each other has a arc shape.

18. The multi-layer piezoelectric element as in one of claims 14-17,

 wherein a radius of curvature of the arc shape is in a range from 0.5 to 10 mm.

19. The multi-layer piezoelectric element as in one of claims 1-18,

20 wherein a ratio (α_1/α_2) is not less than 0.9 and is below 1 (where α_1 is a thermal expansion coefficient of the metal that constitutes the internal electrode and α_2 is a thermal expansion coefficient of the metal that constitutes
25 the external electrode).

20. The multi-layer piezoelectric element as in one of claims 1-19, further comprising an intermediate layer having a composition different from the internal electrode and the external electrode in a junction between the internal electrode and the external electrode.

21. The multi-layer piezoelectric element according to claim 20;

wherein the intermediate layer is composed of a metal that constitutes the internal electrode and a metal that constitutes the external electrode.

22. The multi-layer piezoelectric element according to claims 20 or 21;

wherein a thermal expansion coefficient α_3 of the intermediate layer satisfy a relation $\alpha_1 < \alpha_3 < \alpha_2$.

23. The multi-layer piezoelectric element as in one of claims 18-22,

wherein a composition of the intermediate layer changes gradually from the composition of the metal of the internal electrodes to the composition of the metal component of the external electrodes.

24. The multi-layer piezoelectric element as in one of claims 19-23,

wherein a metal compound that constitutes the internal electrodes include a main component of the metal compound
5 that constitutes the external electrodes not less than 80% by weight and less than 100% by weight.

25. The multi-layer piezoelectric element as in one of claims 1-24,

10 wherein the internal electrodes are exposed on all side faces of the stack.

26. The multi-layer piezoelectric element as in one of claims 1-25,

15 wherein a metal compound in the internal electrode includes a metal of group 8 to 10 and/or a metal of group 11 as a main component.

27. The multi-layer piezoelectric element according to
20 claim 26;

wherein a proportion M1 (% by weight) of the group 8 to group 10 metal and a proportion M2 (% by weight) of the group 11 of the internal electrode satisfy the relations $0 < M1 \leq 15$, $85 \leq M2 < 100$ and $M1 + M2 = 100$.

25

28. The multi-layer piezoelectric element according to claims 26 or 27;

wherein the group 8 to group 10 metal is at least one kind selected from a group consisting of Ni, Pt, Pd, Rh, Ir, Ru and Os, and the group 11 metal is at least one kind selected from a group consisting of Cu, Ag and Au.

29. The multi-layer piezoelectric element as in one of claims 26-28,

wherein the group 8 to group 10 metal is at least one kind selected from a group consisting of Pt and Pd, and the group 11 metal is at least one kind selected from a group consisting of Ag and Au.

30. The multi-layer piezoelectric element as in one of claims 26-28,

wherein the group 8 to group 10 metal is Ni.

31. The multi-layer piezoelectric element as in one of claims 26-28,

wherein the group 11 metal is Cu.

32. The multi-layer piezoelectric element as in one of claims 1-31,

wherein an inorganic composition which is different

from a metallic compound of the internal electrode is added together with the metallic compound in the internal electrode.

33. The multi-layer piezoelectric element according to
5 claim 32;

wherein a main component of the inorganic composition is perovskite type oxide consisting of PbZrO_3 - PbTiO_3 .

34. The multi-layer piezoelectric element as in one of
10 claims 1-33;

wherein a main component of the piezoelectric layer is a perovskite type oxide.

35. The multi-layer piezoelectric element according to
15 claim 34;

wherein a main component of the piezoelectric layer is the perovskite type oxide consisting of PbZrO_3 - PbTiO_3 .

36. The multi-layer piezoelectric element as in one of
20 claims 1, 4, 5, 9 and 14;

wherein ends of the first internal electrodes are exposed on one side face of the stack while grooves are formed on said one side face so as to locate between the second internal electrodes and the first external electrodes,

25 wherein ends of the second internal electrodes are

exposed on other side face of the stack while grooves are formed on said one side face so as to locate between the first internal electrodes and the first external electrodes, wherein each of the grooves is filled with an
5 insulating material that has Young's modulus lower than that of the piezoelectric material.

37. A method of producing the multi-layer piezoelectric element according to claims 4 or 5, the method comprising:

10 mixing two or more kinds of material to make mixed materials; and

firing the mixed materials after calcining at a temperature not lower than the lowest melting point of the materials and not higher than the melting point of the other
15 material.